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An Experimental Data Block Switching System

By W. J. KROPFL

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In a companion paper, J. R. Pierce has described a novel data communication network which makes use of a hierarchy of interconnected rings or loops. The basic elements necessary to realize this network are called "A," "B," and "C" stations. Data blocks are circulated on closed loops formed by the interconnection of "A" and "B" stations. The "B" stations provide user access to the network while one "A" station on each loop performs supervisory functions. Isolated loops are interconnected by "C" stations. This paper describes an experimental hardware implementation of specific "A" and "B" station designs which operate via a T1 carrier system loop. A hog prevention technique is incorporated into the system which prevents any group of stations from monopolizing a loop. A likely "C" station realization and loop transferring algorithm is outlined. A bypass box which would automatically remove malfunctioning stations from the loop is also described.

I. GENERAL INFORMATION

A new type of data communication network has been described in a companion paper by J. R. Pierce.[1] It uses asynchronous multiplexing, buffered switching, and a distributed control system.

In this loop switching system, users are connected to the network by stations which are interconnected by a closed loop transmission line as shown in Fig. 1. Data is entered into and taken from the system in fixed-size blocks. Each data block consists of a unique synchronization word and a header which contains source and destination addresses as well as control information.

Each loop contains an "A" station which serves to close the loop, selectively repeating messages around the loop, and provides clocking and synchronizing information for all messages on the loop.

Another type of station, called a "B" station, utilizes the clock and

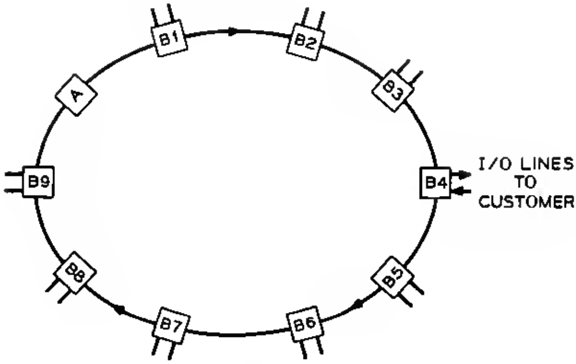


Fig. 1—Basic closed loop transmission network.

synchronizing information provided from the "A" station to write message blocks onto and read message blocks from the transmission loop.

A third type of station, called a "C" station, is used to transfer message blocks between loops. It also supervises the routing of messages through a maze of loops to their ultimate destination.

Laboratory models of the "A" and "B" stations have been designed and built to implement an experimental version of the data loop network described above. This paper describes the essential external features of this hardware and a probable "C" station configuration.

It should be noted the work reported on herein is solely a research project to test the feasibility of the concepts and to discover any unforeseen problems.

II. CONTROL FEATURES

2.1 *Message Format*

The message formats and headers shown in Fig. 2 were chosen to keep the "B" station as simple as possible, since it is the most numerous component in the system. The first three words after the start of the block SYNC word are used for supervisory and current (or local) loop addressing functions.

When traffic is confined to a single loop or to the same local loop, the local message format is used which consists of a local loop header immediately followed by N bytes of useful data. For any given network, N is fixed and was made equal to 54 for the loop described herein.

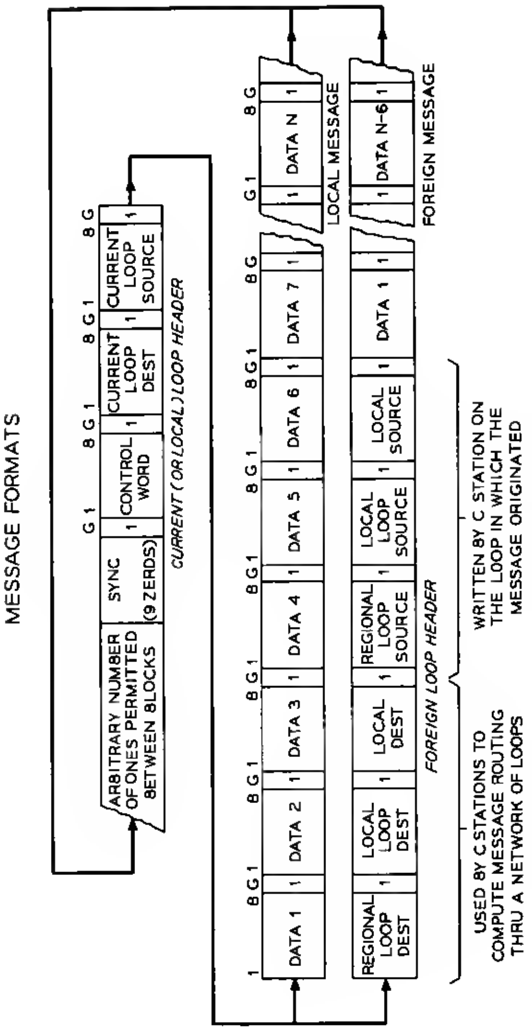


Fig. 2—Message formats.

When addressing a station on a different loop the foreign message format shown in Fig. 2 is used. It consists of a current loop header and a foreign loop header followed by $N - 6$ bytes of data. The contents of the foreign header is used by the "C" stations to pass the message from loop to loop to its ultimate destination.

The first word of each message block is a control word which is subdivided into fields that carry a coded representation of the status of the message block such as whether the block is vacant or full, private or common, and other conditions to be described later. The format of the Data Block Control Word (DBCW) and its control fields is summarized in Table I.

2.2 *Loop Synchronization*

The following synchronization scheme was chosen to make the system compatible with the Bell System's T1 carrier system.[2,3] As shown in Fig. 2, the message block is composed of 8-bit words which are always preceded by a guard bit. This prevents long strings of zeros which would cause the T1 carrier repeaters[4] to lose clock synchronism. The guard bit also allows one to construct a very simple loop synchronization scheme. A start-of-block sync pulse is generated whenever NINE consecutive zeros followed by a ONE are detected, with the result that an arbitrary number of ONEs are permitted between blocks. This allows the system to operate over large variations in loop length.

Table I—Data Block Control Word Format

12	34	56	78		
TC					Type of Message Control Field (2 bits)
	LC				Loop Vacant-Full Control Field (2 bits)
		SB			Spare Bits (2 bits)
			HC		Hog Prevention Control Field (2 bits)
00				PM	Private Message
10				CM	*Common Message
01				UFM	Undeliverable Foreign Message, Foreign Source & Destination Interchanged
11				SCM	*Special Common Message, can be written only via an "A" or "C" Station
	00			VCC	Block Vacant
	10			FCC1	Block Full
	01			FCC2	Block Full and Passed an "A" Station Once
	11			FCC3	Block Full and Passed an "A" Station Twice, Current Loop S & D Interchanged

* Valid for within loop traffic only

III. "B" STATION FUNCTIONS

The main function of a "B" station is to provide an access port to the data loop network. It permits a user to read and write fixed-length message blocks under the supervision of a DBCW. Two general types of messages, namely private and common, are provided to facilitate message handling by the network. A private message, as the name implies, is used for personal or nonpublic communication between individual stations. The common message is used to broadcast the same message to a number of stations on the same loop. The main functional operations of a "B" station are described below and their corresponding logical equations are summarized in Table II.

3.1 *Reading Private Message Blocks*

If a "B" station detects a full block and recognizes the current loop destination address as its own, a message can be read from the data loop if the station's ReaD ReQuest line is enabled. The current loop source address and data is made available on the Parallel and Serial OUTput lines. A timing chart for both the Parallel and Serial Read STroBe lines and the terminal ReaDing gate is given in Fig. 3 together with a diagram summarizing the I/O signals needed to interface to a "B" station. The contents of the DBCW are stored in a register and made available during the entire read cycle on the Control Word OuTput lines. The station acknowledges reading a block by writing a block vacant mark into the DBCW's LC field.

3.2 *Reading Common Message Blocks*

A full block that is marked as being a common or special common message can be read by any station on the loop between the sender and the station nominally addressed, provided its Common Read ReQuest line is enabled. The nominally addressed station always marks the block empty to prevent its further propagation on the loop whether it is read or not. In other respects reading proceeds as described in the paragraph above. These messages can only be used for within-loop traffic. They will not be treated as foreign messages when received by a "C" station. A special common message is reserved for system use and can be written only by an "A" or "C" station. Its purpose is to provide a means by which system status information can be efficiently transmitted about a loop so that economical network management and supervision schemes can be implemented. For example, it would be useful in setting up loop testing, billing, and automated maintenance

TABLE II—SUMMARY OF A AND B STATION LOGIC

Text Key	For Station	If	Set DBCW To			Then
			TC	LC	H1-H2	
3.1	B	(VCCD−) (RDRQ+) (TDAD+)		VCC		Read DBCW, Source & Data
3.2	B	(VCCD−) (CRRQ+) (TC1D+)				Read DBCW, Source & Data
3.2	B	(VCCD−) (TDAD+) (TC1D+)		VCC		
3.3	B	(VCCD+) (WRRQ+) (ENWR+)	CWIN	FCC1		Write Dest, Source, Data & then set HPFF
3.5 (*i*)						
3.5 (*iii*)		Where (ENWR+) = (HCZD+) + (HPFF−)				
3.5 (*ii*)	B	(VCCD−) (WRRQ+) (HPFF−)			1	
3.5 (*v*)	B	(HCZD+)				Reset HPFF
3.5 (*iv*)	A				H2 0	
4.1 (*i*)	A	FCC1D+		FCC2	H2 0	
4.1 (*ii*)	A	FCC2D+		FCC3	H2 0	Interchange Local S & D
4.1 (*iii*)	A	FCC3D+		VCC	H2 0	

Mnemonics not used elsewhere in text:
- ENWR Enable Write
- HCZD HC Field Zero Detected
- TC1D TC Field Bit 1 Detected
- TDAD Terminal Destination Address Detected

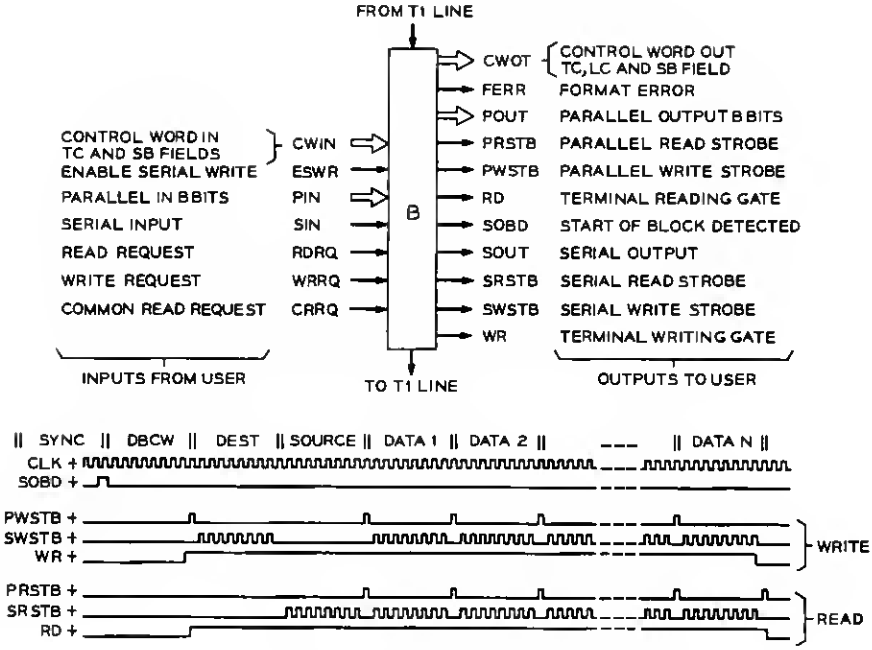


Fig. 3—"B" station I/O signals and timing diagram.

procedures. The common message feature can be useful on special purpose loops where a number of stations wish to share a common data base such as when driving slave-type display systems.

3.3 *Writing Message Blocks*

A message is written when a station, whose WRite ReQuest line is enabled, detects a vacant block. When this occurs a block-full marker is written into the DBCW's LC field. The type of message code to be written (see Table I) is determined by the status of the Control Word IN lines and is written into the DBCW's TC field. The current loop destination address and data are entered, from a user's buffer, through either the Parallel INput or Serial INput lines as determined by the logic level of the Enable Serial WRite line. The current loop source address is hard-wired within the station in order to provide positive sender identification. The timing for botb the Parallel and Serial Write STroBe pulses and the terminal WRiting gate is given in Fig. 3.

3.4 *Format Error Detection*

The "B" station contains logic to continuously monitor the format

of the data loop. This is done by counting the number of words between consecutive start of block syncs. If the number of words is shorter than that needed to store a message block or longer than needed to store two blocks, a format error signal is generated. The "B" station also generates a format error if it detects a missing clock pulse. This error signal notifies the user as to the operational condition of the loop.

3.5 *Prevention of Data Loop Hogging*

Loop hogging can occur when certain send-receive patterns are established on a loop. For example, in Fig. 1, stations B2 and B5 through B8 cannot write messages onto the loop if B1 and B4 transmit continuously to B3 and B9 respectively. This problem can be solved if, after any "B" station sends a message, it is prevented from sending another message until all other write requests on the loop are acknowledged. This was implemented by manipulating a 2-bit Hog prevention Control (HC) field in the DBCW of each message block in the following manner;

(*i*) When a "B" station writes a message, a Hog Prevention Flip-Flop (HPFF) in that station is set to ONE. The block's HC field, however, is circulated on the loop unmodified.

(*ii*) If a "B" station on the loop has its WRite ReQuest line enabled when a full block is detected and if its HPFF is set to
- (a) ZERO, HC2 of the Hog prevention Control field is set to ONE;
- (b) ONE, nothing is done to HC2.

(*iii*) If a "B" station detects a vacant block and if the HC field is
- (a) ZERO, writing is independent of the state of HPFF;
- (b) NOT ZERO, the "B" station can write if and only if HPFF = 0.

(*iv*) When a data block passes an "A" station the contents of HC2 become the contents of HC1 and ZERO becomes the contents of HC2, i.e., (HC2) → (HC1) and 0 → (HC2).

(*v*) Whenever a "B" station detects an HC field whose contents are zero, its HPFF is reset; if it writes into this block, its HPFF will be set.

The scheme outlined above prevents any group of stations from monopolizing a loop. The service rendered is equitable in that the resources of the loop are divided equally among all of the users requesting service. If M users have their WRRQ lines enabled, each user is guaranteed that he will have to wait for no more than M vacant blocks to pass before he can write—provided no new WRRQ lines are enabled while the station is waiting. It should be noted at this time that vacant

blocks are generated, not only by a "B" station that reads a message addressed to it from the loop, but also by an "A" station (see Section 4.1) which detects three passes of the same message block. Considering this and the worst traffic situation that can occur on a loop, namely that all stations continually write messages to busy or nonexistent stations, we obtain, for an N-station loop, a maximum possible waiting time of $3N$ message block periods between consecutive write permits.

3.6 *Basic Delay Properties of Loop*

From a user's point of view, message string delay, D_S, is probably the most important variable by which system performance can be evaluated. For a given loop, D_S is the total time encountered in sending a message string consisting of K blocks between two stations on the same loop, and is given by

$$D_S = KD_A + D_P \tag{1}$$

where D_A is an average access delay for the writing interval and D_P is a propagation delay.

Propagation delay, D_P, is the time interval from when a message is written onto a loop until it arrives at its destination on the same loop and is simply equal to the number of delay elements between the sender and receiver. Each "B" station contains an 18-bit shift register which results in an 18-bit delay for each station on the loop.

Access delay, D_A, is defined as the time lapse between when a station requests and is subsequently granted permission to write a message block onto the loop. If a station requests service continuously, D_A is the time between two consecutive write permits for that station. It is a traffic-dependent random variable and as such requires statistical assumptions concerning user behavior to model it in a complete and rigorous manner. This random delay has been characterized in a study by J. F. Hayes and D. N. Sherman[5] for a data loop proposed by J. R. Pierce,[1] which did not include the above-mentioned anti-hogging scheme.

It has been demonstrated in the section above, however, that the constraint placed on loop traffic by the anti-hogging control scheme places a maximum limit on this delay of $3N$ blocks and is independent of user behavior. We thus have a worst case access delay of

$$(D_A)_{\max} < 3N * L/C \tag{2}$$

for a "B" station on a loop with the following characteristics:

N = number of stations on the loop,

L = block length in bits (including header, message body, guard bits, and filter bits),

C = loop bit rate capacity in bits/second.

The maximum propagation delay possible for a given loop is

$$(D_P)_{\max} < S * L/C \tag{3}$$

where S is tbe number of message block sectors circulating on the loop.

We now obtain a maximum message string delay of

$$(D_S)_{\max} < (3N * K + S) * L/C. \tag{4}$$

Although these results can be used to estimate worst case loop delays under saturated traffic conditions, tbey are much too conservative for use on local loops. Few stations on a local loop will send messages continuously. Equation (2) can therefore be multiplied by an average utilization factor,

$$\mu = 1/N \sum_{1}^{N} \mu_i \tag{5}$$

wbere μ_i is the probability that station i bas its WRRQ enabled, and results in the following

$$D_A < 3\mu N * L/C \tag{6}$$

more realistic average access delay. Further analysis requires statistics concerning user behavior.

The worst case traffic assumption that led to the factor 3 in the above analysis is rather conservative; for example, it may be replaced by unity if circumstances are such that one can assume that all messages are properly addressed and encounter no busy stations.

IV. "A" STATION FUNCTIONS

4.1 *Supervision of Unclaimed Messages*

One of the primary functions of an "A" station is to dispose of undeliverable messages that occur due to being addressed to busy or nonexistent stations. This is done in the following manner:

(*i*) When a message passes an "A" station for the first time, its DBCW is marked to this effect as shown in Table I.

(*ii*) If the same message passes an "A" station twice, the destination and source addresses are interchanged and the DBCW marked to this effect. This sends the message back to the sender and thus serves as a station busy signal.

(*iii*) If the same message passes an "A" station for the third time, the block is marked vacant.

4.2 *Line Buffering*

In order to close the data loop, the "A" station must contain a loop closing buffer. The size of the buffer is dictated by the need to guarantee that the total loop bit capacity will always be large enough to store an integral number of data blocks. In the experimental model the buffer size is 512 bits and is fixed. The fixed buffer can result in a variable gap between messages, depending upon the number of stations on the loop. In an actual operating system it will probably be desirable to make this a variable length buffer in order to compensate for large variations in loop bit capacity due to changes in loop length. Loop length would be subject to temperature variations and changes due to taking malfunctioning stations off the loop. In any case, since the proposed synchronization scheme is insensitive to variations in loop length, this becomes a separate problem.

Another problem can present itself at an "A" station when closing the loop. Data errors will sometimes result due to phase difference variations between the "A" station's internal crystal clock and the received T1 carrier clock. In short loops this difference is nearly constant and can be compensated for by delaying the T1 clock by a fixed amount. This was done in the laboratory model. On long loops this phase difference will vary due to repeater-induced clock jitter as well as those variations discussed in the previous paragraph. This problem can be eliminated, using a four-bit elastic store[6] in the "A" station, by reading data into a buffer under the control of the incoming T1 repeater clock and reading out under control of the "A" station's crystal clock. The buffer must be initialized during a format loop cycle so that the buffer cell being read into is two bits removed from the cell being read out. This prevents data errors by eliminating the possibility that a buffer cell will be overwritten before its contents are used by the "A" station.

4.3 *Formatting*

When an "A" station detects a format error signal, it reformats the loop. In cases where it is possible to have only ONE data block circulating on the loop, reformatting is easily done by filling the line with all ONEs and then inserting a sequence of nine ZEROs. If the error condition persists, the loop is down and some maintenance procedures must be initiated.

In order to perform the various functions described above, an "A"

station needs a substantial portion of the logic contained in a "B" station. Therefore, the elements required to perform these operations are incorporated into one of the loop's "B" stations. A block diagram summarizing the additional logic needed is shown in Fig. 4.

V. "C" STATION FUNCTIONS

The primary purpose of a "C" station is to provide a means for interconnecting isolated loops. A likely realization of a "C" station is shown in Fig. 5. It consists of two "B" stations interconnected by a Buffer Memory and Controller. Messages destined for a station outside its own particular local loop are read and subsequently rewritten by "C" stations from loop to loop in the same manner as local interloop traffic. Buffering is needed because messages will often be delayed in going from one loop to another since messages already on the adjacent loop have the right of way. Buffering also has the desirable effect of allowing adjacent loops to operate at different bit rates.

If a network consists of a hierarchy of loops, a particularly simple foreign addressing scheme results. Such a network due to Pierce[1] is shown in Fig. 6. Individual subscribers are connected together by a local loop. The local loops are interconnected by the "LC" stations forming regional loops which are in turn connected by "RC" stations to form a national loop.

5.1 *Loop Transferring Algorithms*

To gain some insight into how a "C" station can be designed using the "B" station hardware described above, let us send a foreign message from X (R1, L2, B1) to Y (R4, L2, B2) in Fig. 6, examining the address portion of the message at each step.

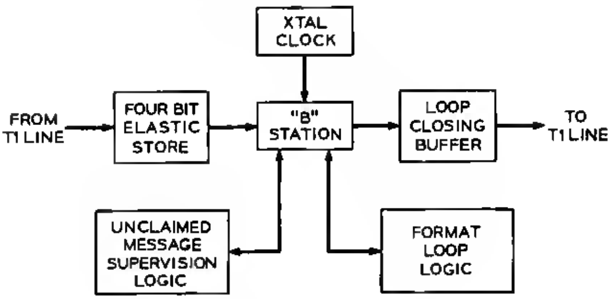


Fig. 4—"A" station.

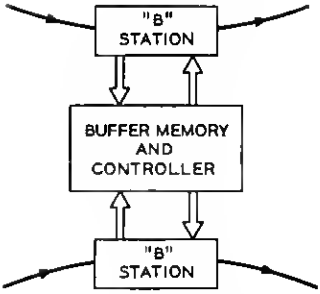
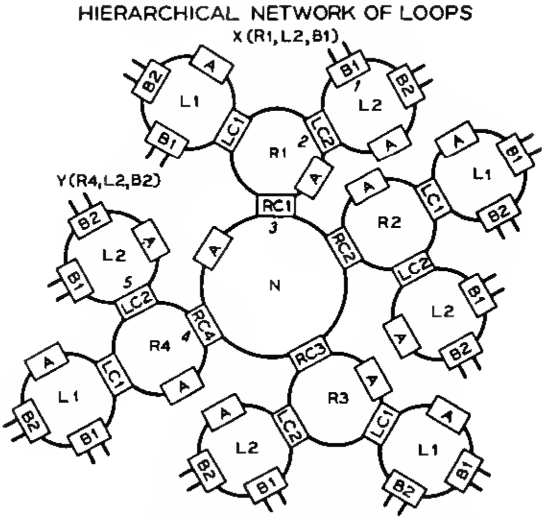


Fig. 5—"C" station.

Station X starts the process by writing a private message, with the header shown in *step 1* of Fig. 6, to its local loop "C" station. Note that all private messages sent and received by the local loop portion of a local "C" station are declared foreign.



FOREIGN MESSAGE HEADER

SYNC / DBCW (STEP)	CLD	CLS	RLD	LLD	LD	RLS	LLS	LS
1 X TO L	LC	.B1.	R4	L2	B2	---	---	---
2 L TO R	.RC.	.LC2.	R4	L2	B2	.RC1.	.LC2.	B1
3 R TO N	R4	.RC1.	R4	L2	B2	RC1	LC2	B1
4 N TO R	L2	.RC.	R4	L2	B2	RC1	LC2	B1
5 R TO L	B2	.LC.	R4	L2	B2	RC1	LC2	B1

Fig. 6—Foreign addressing scheme.

The message is then read by the addressed "C" station if its buffer is not full. The LC field of the DBCW is checked to make certain that the current loop source and destination addresses have not been interchanged, i.e., LC $\neq$ FCC3. The various control field codes are defined in Table I.

The message header is then operated upon by the appropriate procedure denoted by entry point SW shown in Fig. 7. The position of switch SW depends upon which loop is being traversed. The message with its new header is now written onto the adjacent loop. By following the process to its conclusion one can easily see that the algorithm given in Fig. 7 always gets the message to its designated destination address if no "C" station with a full buffer is encountered. The addresses bracketed by periods in Figs. 6 and 7 are defined and written at the step indicated by the network's "B" or "C" stations and cannot be altered by a customer. This is done to insure proper message source identification. They and the user defined addresses of *step 1* are subsequently manipulated by the network's "C" stations as shown in Fig. 6.

5.2 *Undeliverable Foreign Messages*

If a destination "B" station, or any "C" station, encountered by a message block is busy, the condition is detected by an "A" station which interchanges the current loop source and destination addresses and marks this fact by making LC = FCC3. As a result, the message is sent back to the last "C" station from which it came. This "C" station examines the contents of the DBCW and upon finding LC = FCC3 takes one of the following alternate corrective actions:

(*i*) If this is the message's first encounter with an obstacle, i.e., TC = PM, the message is read into the "C" station's buffer memory where its foreign source and destination addresses are interchanged. The message is also marked as being an undeliverable foreign message. The process then proceeds as directed by entry point SW in Fig. 7 and thus sends the message back to the sender.

(*ii*) If the message has already been marked as being an undeliverable foreign message, i.e., TC = UFM, the message is not read into the buffer memory. Therefore, any message that encounters two busy stations as it wanders through a maze of loops is destroyed.

5.3 *Buffer Status Controls the Relaying of Messages*

In the system above messages can be rejected and even destroyed by the system. A message should be rejected only due to encountering

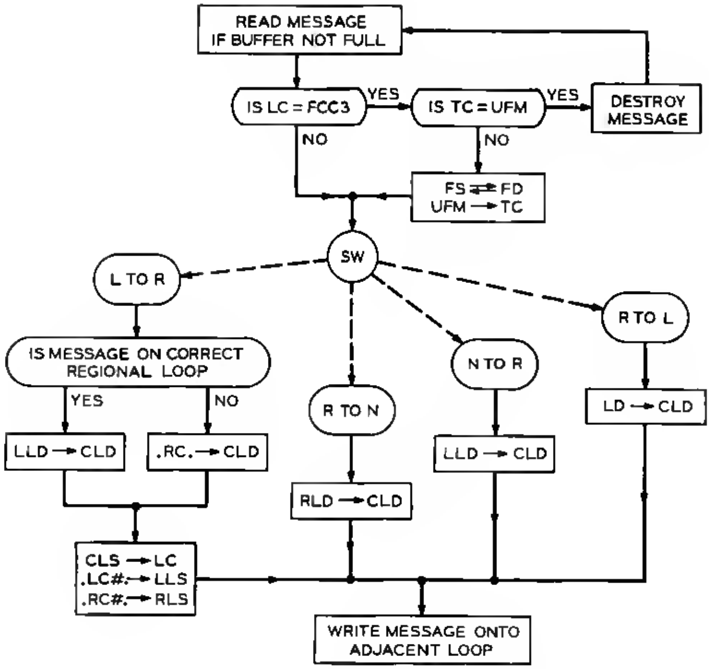


Fig. 7—"C" station loop transferring algorithms.

a busy destination "B" station. This ideal system will be approached as system "C" station buffer capacity is increased.

The following strategy can be employed to prevent message loss due to blockage by the system even in the presence of limited "C" station buffering.

Each "C" station buffer is divided into two sections—an upward buffer and a downward buffer. As their names imply these buffers pass messages up and down the hierarchy of loops. When one of these "C" station buffers becomes *nearly* full, its station sends a buffer full status signal, via a special common message, to all the other stations on the loop from which the buffer in question receives messages.

This buffer status information is used by the other "C" stations to prevent the relaying of messages to a station with a full buffer.

The buffer full status signal is sent before the buffer is completely full because messages destined for the station may still be in transition—the maximum number of messages in transit being the capacity of the loop.

The "C" station with the full buffer later sends a buffer clear status

signal to all stations on its loop when its buffer bas room for additional messages.

5.4 *Redundant Loops*

The reliability and capacity of the hierarchical system just described would be substantially improved if redundant pathways were added. The alternate message routing and loop doubling schemes outlined in Pierce's paper[1] can be readily incorporated into the system for this purpose.

VI. BYPASS BOX

Loop integrity could be more readily insured and maintenance more easily performed if loop ByPass "BP" boxes were placed at strategic locations in the network. The logic of these boxes is given below. Such boxes would not only protect the loop against "B" station malfunctions but also protect the system against faulty repeaters and cables.

The "B" station in Fig. 8 would be bypassed by the "BP" box if any of the following conditions occur:

(*i*) Missing clock pulses are detected at IN2 but NOT detected at IN1 within a present period of time.

(*ii*) Varying data pulses are detected at IN1 but NOT detected at IN2 within a preset period of time.

(*iii*) Could be tripped manually or automatically from a central office to isolate some of the more subtle and unpredictable faults which will undoubtedly occur as in any system.

A "BP" box can be tripped only by a fault which occurs on tbe section of the loop it parallels. When it is tripped a delay equivalent to the bypassed section must be introduced into the loop. This could be done by baving a fixed delay within the "BP" box. It may however be advantageous, especially from an installation cost viewpoint, to add some loop length measurement logic to an "A" station and bave it

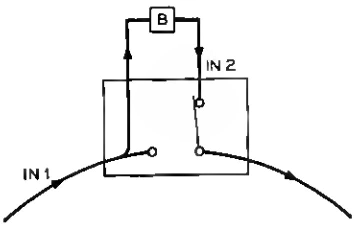


Fig. 8—Loop bypass box.

control a variable length loop closing buffer in order to compensate for the delay. Once a "BP" box has been tripped it can be reset only by the carrier. Normally the carrier would trip or reset a "BP" box only when the loop is being formatted. This is necessary to prevent the destruction of messages that may be currently circulating on the loop.

The notion of using the detection of missing clock pulses and the absence of missing data pulses to transmit information about major loop malfunctions are especially attractive because of the ease with which they can be implemented. Their use, however, requires careful consideration of T1 repeatered line performance when subjected to sparse or no input pulses.

6.1 *Repeater Performance with No Input Pulses*

If no input pulses are applied to a repeater, several possible consequences result. A number of these are summarized below.

A repeater may go into self-oscillation at approximately 10 KHz. This state would produce missing clock pulses which would be sensed by bypass condition *i* above.

An eight-out-of-eight pulse train may be generated due to cross talk from the clock circuit on the other side of the repeater. Line repeaters contain two complete regenerators in one case which share a common voltage regulator. This state would be sensed by bypass condition *ii*.

A regenerator which goes into self-oscillation may draw an excessive current from the voltage regulator thus adversely affecting the operation of its companion repeater. This condition must be eliminated or careful consideration must be given to how companion regenerators are used in the network.

A new T1 repeater[7] has recently been developed and is currently undergoing field trials. The availability of this repeater will eliminate many of the problems described above because it was designed not to oscillate during the absence of an input signal.

VII. HARDWARE PARTICULARS

Two "B" stations and an "A" station have been implemented and interconnected using T1 carrier system repeaters as a component part of the stations. The T1 system uses bipolar pulse transmission techniques to span up to 6000 feet between repeaters and has a bit rate of 1.544 MHz.

The "B" station was built with 56 chips of standard 7400 series TTL circuitry, 6 of which are MSI circuits. The "A" station contains all

the logic of a "B" station plus 7 additional chips needed for message supervision and reformatting control logic and a 512-bit MOS loop closing buffer. A photograph of an experimental "A" station is shown in Fig. 9.

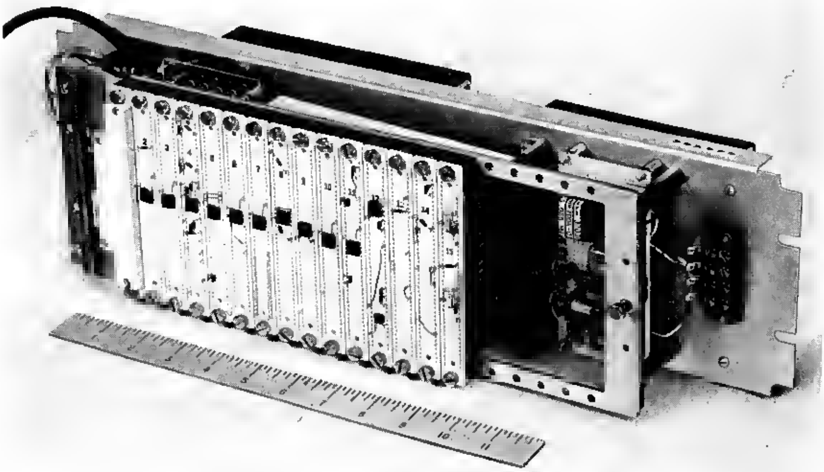


Fig. 9—Experimental "A" station.

A fixed message length of 522 bits was chosen because it allows a complete message to circulate on a loop made by closing an "A" station upon itself. The additional bits in excess of 512 come from the storage inherent within the "B" box portion of an "A" station. Therefore, each local message can accommodate 54 bytes of data while a foreign message contains 48 bytes of useful data. The bit rate and message block size can be easily altered if needed. The bit rate is dictated only by the characteristics of the T1 repeaters.

VIII. CONCLUSION

The system described above has been used to interconnect two DDP 516 laboratory computers. The computer interface and hardware for this system are described in a companion paper by C. H. Coker.[8] The equal sharing property of a loop and minimal constraints on the data format and simple addressing scheme allow the user a great deal of flexibility to structure the system to his needs.

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